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Remarks:
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(54) **Transformer with ferrite core and method for driving it**

(57) Provided are an Mn-Zn ferrite in which the core loss is low and Bs is high at high temperatures; a transformer capable of being small-sized and suitable to use at high temperatures; and a method for efficiently driving the transformer. Also provided is a transformer capable of being small-sized and suitable to use in a broad temperature range including high temperatures. Further provided are a high-efficiency transformer capable of being small-sized, in which the core loss in the ferrite core is low and the saturation magnetic flux density is high therein at the temperature at which the transformer is driven; and a high-efficiency driving method for the transformer. Depending on its use, Mn-Zn ferrite to be the ferrite core for the transformers comprises, as the essential components, specific amounts of Fe_2O_3, ZnO and MnO, and, as the side components, specific amounts of SiO_2, $CaCO_3$, Nb_2O_5 and ZrO_2. The core of the transformers is made of the Mn-Zn ferrite.

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Description

[0001] The present invention relates to an Mn-Zn ferrite suitable for transformer cores, in which the core loss is low and the saturation magnetic flux density is high at high temperatures, to a transformer with an Mn-Zn ferrite core which is used in power supplies for switching converters and display monitors, and also to a method for driving the transformer.

[0002] The invention further relates to a transformer with an Mn-Zn ferrite core in which the core loss is low and the saturation magnetic flux density is high at its driving temperature falling between 50 and 70°C or so, and to a method for driving the transformer.

[0003] Mn-Zn ferrites are much used as materials for transformers for various communication appliances, household and industrial appliances, etc. The temperature at which transformers in conventional switching power supplies are used falls between 60 and 100°C, and the switching frequency for the power supplies falls between 10 and 100 kHz. The minimum core loss in transformers is within the practical temperature range, and various studies of additive addition, element substitution, firing condition change and others have heretofore been made so as to lower the core loss in transformers within the practical temperature range (see Japanese Patent Application Laid-Open (JP-A) Hei-8-169756, etc.). With the recent tendency toward small-sized and lightweight switching power supplies, high frequency has become used for switching frequency. Low core loss materials for a frequency falling between 500 kHz and 1 MHz or so have been developed (see JP-A Hei-8-148323, etc.).

[0004] However, since transformers generate heat by themselves and are used in high-temperature conditions, the temperature of the transformer core being actually driven is often high to fall between 80 and 110°C.

[0005] Ferrites for power supplies of that type have been proposed in JP-A Hei-3-141612 and Hei-7-297020. The Mn-Zn ferrites proposed therein have an essential component of ZnO of being not smaller than 10 mol%, and contains an additive of Nb_2O_5 in the former (Hei-3-141612) or Nb_2O_5 combined with ZrO_2 in the latter (Hei-7-297020) and additionally SnO_2 and TiO_2 in an amount of not smaller than 300 ppm, to thereby lower the core loss in those ferrites.

[0006] However, it is still desired that magnetic oxide materials shall satisfy not only low core loss but also high saturation magnetic flux density therein so as to realize small-sized and efficient transformers within the practical temperature range noted above.

[0007] Mn-Zn ferrites having a ZnO content of not smaller than 10 mol% could realize reduced core loss therein, but could not realize increased saturation magnetic flux density within the practical temperature range noted above, especially at a temperature falling between 100 and 110°C.

[0008] In this connection, the core loss reduction in Mn-Zn ferrites could be realized by element substitution of adding SnO_2 and TiO_2 to the ferrites. However, no magnetic oxide materials are known capable of realizing increased saturation magnetic flux density within the practical temperature range noted above.

[0009] On the other hand, where the practical temperature range for magnetic oxide materials is broad, for example, it falls between 20 and 120°C, the materials are indispensably required to satisfy low core loss therein. However, if the saturation magnetic flux density in the materials varies, depending on the temperature at which the power supplies comprising the materials are used, and, as a result, if the permeability of the materials is thereby varied, the inductance of the materials shall vary, depending on the ambient temperature even though the magnetic field around the materials does not vary. For these reasons, therefore, when the materials are used for power smoothing, the ripple in the outputted power will vary, thereby causing the problem that the power-outputting characteristics of the power supplies comprising the materials vary.

[0010] Mn-Zn ferrites having a ZnO content of not smaller than 10 mol% could realize reduced core loss therein, but the temperature-dependent variation in the saturation magnetic flux density in them is large within the practical temperature range noted above.

[0011] For the reasons mentioned above, it is desired to develop ferrites and transformers suitable to use at high temperatures and also in a broad temperature range including high temperatures.

[0012] On the other hand, desired are transformers in which the core loss is low at their driving temperatures under the conditions under which they may generate a small quantity of heat by themselves. For such transformers in that situation, it is still desired to lower the highfrequency core loss in them so as to meet the requirement of small-sized and lightweight switching power supplies. The driving temperature for transformers generally falls between 50 and 70°C. However, with advance knowledge of the generation of heat in transformers, ferrites for transformers may be so designed that the core loss in the transformers comprising them could be the lowest within a temperature range falling between 80 and 100°C (see JP-A Hei-3-141612, Hei-7-297020, Hei-8-169756, etc.). Of those patent publications, JP-A Hei-8-169756 discloses a low core loss Mn-Zn ferrite core which consists essentially of from 25 to 40 mol% of MnO and from 6 to 25 mol% of ZnO with the balance of Fe_2O_3 and contains, as side components, from 0.002 to 0.040 wt.% of SiO_2 and from 0.02 to 0.20 wt.% of CaO and in which the side component elements are segregated to be in the grain boundaries in such a manner that the half width of their concentration distribution is not larger than 10 nm. They say in JP-A Hei-8-169756 that the side components may further include Nb_2O_5, Ta_2O_5, ZrO_2 and V_2O_5. The composition of the samples actually demonstrated in their Examples was so designed that the core loss in them could

be the lowest at 90°C. Briefly, the composition of the essential components in those samples is composed of 53.5 mol% of Fe_2O_3, 34.5 mol% of MnO and 12.0 mol% of ZnO.

[0013]   As in JP-A Hei-8-169756, the ferrite is so designed that the core loss therein could be the lowest at temperatures higher then its driving temperature. However, under the conditions under which transformers may generate a small quantity of heat by themselves, it is necessary that the core loss in the transformers is lower within a temperature range of from 50 to 70°C within which the transformers are driven.

[0014]   To meet the requirement, JP-A Hei-8-191011 discloses an Mn-Zn-Co ferrite in which the core loss is reduced within the driving temperature noted above. The additive oxides that may be in the ferrite include SiO_2, CaO, ZrO_2 and Ta_2O_5.

[0015]   However, the Mn-Zn-Co ferrite in JP-A Hei-8-191011 is still problematic in that the core loss therein within the driving temperature range that falls between 50 and 70°C could not be reduced to a satisfactory level, and therefore requires further studies on it.

[0016]   The first object of the present invention is to provide a ferrite in which the core loss is low and the saturation magnetic flux density is high at high temperatures. The second object is to provide a transformer capable of being small-sized and suitable to use at high temperatures. The third object is to provide a transformer capable of being small-sized and suitable to use in a broad temperature range including high temperatures. The fourth object is to provide a method for efficiently driving the small-sized transformer at high temperatures. The fifth object is to provide a high-efficiency transformer capable of being small-sized, of which the core is made of a ferrite of such that the core loss therein is low and the saturation magnetic flux density therein is high within the driving temperature range (between 50 and 70°C) for the transformer. The sixth object is to provide a method for efficiently driving the transformer.

[0017]   The objects mentioned above are attained by the invention which provides the following:

(1) A ferrite consisting essentially of iron oxide in an amount of from 53 to 55 mol% calculated as Fe_2O_3, zinc oxide in an amount of from 6.5 to 9.5 mol% calculated as ZnO, and manganese oxide, and containing, as side components, silicon oxide in an amount of from 80 to 150 ppm calculated as SiO_2, calcium oxide in an amount of from 600 to 1000 ppm calculated as $CaCO_3$, niobium oxide in an amount of from 150 to 400 ppm calculated as Nb_2O_5, and zirconium oxide in an amount of from 40 to 300 ppm calculated as ZrO_2.

(2) A transformer of which the core is made of a ferrite that consists essentially of iron oxide in an amount of from 53 to 55 mol% calculated as Fe_2O_3, zinc oxide in an amount of from 4.0 to 9.5 mol% calculated as ZnO, and manganese oxide, and contains, as side components, silicon oxide in an amount of from 60 to 200 ppm calculated as SiO_2, calcium oxide in an amount of from 300 to 1200 ppm calculated as $CaCO_3$, niobium oxide in an amount of from 50 to 500 ppm calculated as Nb_2O_5, and zirconium oxide in an amount of from 10 to 450 ppm calculated as ZrO_2, and in which the saturation magnetic flux density (direct current) in the ferrite at a temperature falling between 100 and 120°C is not smaller than 410 mT.

(3) The transformer of (2), wherein the minimum core loss in the ferrite is within a temperature range falling between 100 and 110°C and the minimum core loss (at a frequency of 100 kHz) is not larger than 300 kW/m³.

(4) The transformer of (2) or (3), wherein the ferrite consists essentially of iron oxide in an amount of from 53 to 55 mol% calculated as Fe_2O_3, zinc oxide in an amount of from 6.5 to 9.5 mol% calculated as ZnO, and manganese oxide, and contains, as side components, silicon oxide in an amount of from 80 to 150 ppm calculated as SiO_2, calcium oxide in an amount of from 600 to 1000 ppm calculated as $CaCO_3$, niobium oxide in an amount of from 150 to 400 ppm calculated as Nb_2O_5, and zirconium oxide in an amount of from 40 to 300 ppm calculated as ZrO_2.

(5) A transformer of which the core is made of a ferrite that consists essentially of iron oxide in an amount of from 53 to 55 mol% calculated as Fe_2O_3, zinc oxide in an amount of from 2.0 to 8.0 mol% calculated as ZnO, and manganese oxide, and contains, as side components, silicon oxide in an amount of from 60 to 200 ppm calculated as SiO_2, calcium oxide in an amount of from 300 to 1200 ppm calculated as $CaCO_3$, niobium oxide in an amount of from 50 to 500 ppm calculated as Nb_2O_5, and zirconium oxide in an amount of from 10 to 450 ppm calculated as ZrO_2, and in which the absolute value of the temperature-dependent coefficient of the saturation magnetic flux density (direct current) in the ferrite at a temperature falling between 20 and 120°C is not larger than 1.6 mT/°C.

(6) A method for driving a transformer of which the core is made of a ferrite that consists essentially of iron oxide in an amount of from 53 to 55 mol% calculated as Fe_2O_3, zinc oxide in an amount of from 4.0 to 9.5 mol% calculated as ZnO, and manganese oxide, and contains, as side components, silicon oxide in an amount of from 60 to 200 ppm calculated as SiO_2, calcium oxide in an amount of from 300 to 1200 ppm calculated as $CaCO_3$, niobium oxide in an amount of from 50 to 500 ppm calculated as Nb_2O_5, and zirconium oxide in an amount of from 10 to 450 ppm calculated as ZrO_2, wherein the transformer is driven at a temperature falling between 60 and 120°C, at a frequency falling between 20 and 500 kHz and in an exciting magnetic flux density falling between 200 and 500 mT.

(7) The method for driving a transformer of (6), wherein the ferrite for the core of the transformer consists essentially of iron oxide in an amount of from 53 to 55 mol% calculated as Fe_2O_3, zinc oxide in an amount of from 6.5 to 9.5 mol% calculated as ZnO, and manganese oxide, and contains, as side components, silicon oxide in an amount of

from 80 to 150 ppm calculated as SiO_2, calcium oxide in an amount of from 600 to 1000 ppm calculated as $CaCO_3$, niobium oxide in an amount of from 150 to 400 ppm calculated as Nb_2O_5, and zirconium oxide in an amount of from 40 to 300 ppm calculated as ZrO_2.

(8) A transformer of which the core is made of a ferrite that consists essentially of iron oxide in an amount of from 54 to 56 mol% calculated as Fe_2O_3, zinc oxide in an amount of from 6 to 11 mol% calculated as ZnO, and manganese oxide, and contains, as side components, silicon oxide in an amount of from 80 to 150 ppm calculated as SiO_2, calcium oxide in an amount of from 600 to 1000 ppm calculated as $CaCO_3$, niobium oxide in an amount of from 150 to 400 ppm calculated as Nb_2O_5, and zirconium oxide in an amount of from 40 to 300 ppm calculated as ZrO_2, and in which the saturation magnetic flux density (direct current) in the ferrite at 60°C is not smaller than 480 mT, the minimum core loss in the ferrite is within a temperature range falling between 50 and 70°C and the minimum core loss (at a frequency of 100 kHz) is not larger than 260 kW/m³.

(9) The transformer of (8), wherein the zinc oxide content of the ferrite falls between 6 and 9.5 mol% calculated as ZnO.

(10) The transformer of (8) or (9), wherein the saturation magnetic flux density (direct current) in the ferrite at 60°C is not smaller than 500 mT.

(11) A method for driving a transformer of any one of (8) to (10) at a temperature falling between 50 and 70°C, at a frequency falling between 20 and 500 kHz and in an exciting magnetic flux density falling between 125 and 500 mT.

[0018] In JP-A Hei-8-169756, proposed is an Mn-Zn ferrite having a ZnO content of from 6 to 25 mol%, in which the core loss is low at temperatures around 90°C. In this, however, the samples concretely demonstrated in Examples have a ZnO content of 12.0 mol% and an Fe_2O_3 content of 53.5 mol%. Therefore, the invention of JP-A Hei-8-169756 shall be obviously differentiated from the present invention.

[0019] In JP-A Hei-8-148323, shown are magnetic materials having a reduced degree of core loss within a range of medium frequency to high frequency bands. In this, the comparative samples referred to in Examples have a ZnO content of 8.0 mol%. However, nothing that relates to addition of Nb_2O_5 to ferrites is referred to in JP-A Hei-8-148323. Therefore, the technical idea for the invention of JP-A Hei-8-148323 is basically different from that for the present invention.

[0020] In JP-A Hei-8-191011, shown are Mn-Zn-Co ferrites for transformers in which the core loss at the driving temperature for the transformers is reduced. However, nothing that relates to addition of Nb_2O_5 to the ferrites is referred to in JP-A Hei-8-191011. Therefore, the technical idea for the invention of JP-A Hei-8-191011 is also basically different from that for the present invention.

[0021] In the accompanying drawings:

Fig. 1 is a graph showing the temperature-dependent variation in the core loss in ferrite samples; and

Fig. 2 is a graph showing the temperature-dependent variation in the saturation magnetic flux density in ferrite samples.

[0022] The present invention is described in detail hereinunder.

[0023] The ferrite core material for one embodiment of the transformers of the invention comprises a ferrite having the composition mentioned below, in which the saturation magnetic flux density Bs (direct current) at a temperature falling between 100 and 120°C is not smaller than 410 mT.

Essential Components:

[0024]

Iron oxide in an amount of from 53 to 55 mol% (calculated as Fe_2O_3),
Zinc oxide in an amount of from 4.0 to 9.5 mol%, preferably from 6.5 to 9.5 mol% (calculated as ZnO), and
Manganese oxide as the balance (calculated as MnO).

Side Components:

[0025]

Silicon oxide in an amount of from 60 to 200 ppm, preferably from 80 to 150 ppm (calculated as SiO_2),
Calcium oxide in an amount of from 300 to 1200 ppm, preferably from 600 to 1000 ppm (calculated as $CaCO_3$),
Niobium oxide in an amount of from 50 to 500 ppm, preferably from 150 to 400 ppm (calculated as Nb_2O_5), and

Zirconium oxide in an amount of from 10 to 450 ppm, preferably from 40 to 300 ppm (calculated as ZrO_2).

[0026] The ferrite composition is characterized by high Bs at high temperatures noted above and by reduced core loss in a high temperature range (falling between 100 and 110°C).

[0027] Therefore, transformers of which the core is made of the ferrite of that type noted above can be efficiently driven even when the temperature of the ferrite core reaches 80 to 110°C due to the heat generated by the transformer themselves or in high-temperature conditions, and therefore, the transformers are suitable to use at high temperatures. More concretely, since the ferrite material realizes high Bs at high temperatures, the ferrite cores in the transformers can be small-sized, and therefore the transformers themselves can be small-sized. In addition, since the core loss in the transformers is small at high temperatures, the power to be consumed by the transformers at high temperatures and also the heat to be generated by them can be reduced.

[0028] Bs (direct current) in the ferrite having the composition mentioned above is not smaller than 410 mT at a temperature falling between 100 and 120°C. As in Fig. 2, Bs linearly varies relative to the ambient temperature change, and its temperature-dependent coefficient is negative. Therefore, Bs in the ferrite must be at least 410 mT at 120°C. Preferably, Bs in the ferrite within the temperature range noted above is at least 415 mT, more preferably at least 420 mT. Though not specifically defined, the uppermost limit of Bs may be 500 mT or so. The temperature-dependent coefficient of Bs is represented by the following equation in which Bs [100°C] indicates the value of Bs at 100°C and Bs [120°C] indicates the value of Bs at 120°C. The coefficient generally falls between -1.6 and 0 mT/°C or so.

Temperature-Dependent Coefficient

= (Bs [120°C] - Bs [100°C])/(120°C - 100°C)

[0029] Where the core loss in the ferrite is measured at a frequency falling between 20 and 500 kHz (preferably between 75 and 150 kHz) and in an exciting magnetic flux density falling between 200 and 500 mT (preferably between 200 and 350 mT), its minimum value is within a temperature range falling between 100 and 110°C, and the core loss thus measured (at 100 kHz and in 200 mT) is at most 300 kW/m^3, preferably at most 270 kW/m^3. Though not specifically defined, the lowermost limit of the core loss may be 200 kW/m^3 or so.

[0030] As opposed to the ferrite composition noted above, the core loss in the others of which the composition of the essential components falls outside the ranges noted above is high and Bs therein often lowers depending on the composition of the essential components. Many conventional Mn-Zn ferrite materials for transformers have a ZnO content of not smaller than 10 mol% for the purpose of reducing the core loss in them. As opposed to those, the present invention is characterized by the lowered amount of ZnO in the ferrite, by which Bs in the ferrite is increased. Therefore, in the invention, if the ZnO content of the ferrite is larger than 9.5 mol%, Bs in the ferrite shall lower. On the other hand, however, if the ZnO content of the ferrite is smaller than 4.0 mol%, the core loss in the ferrite will increase. If the Fe_2O_3 content of the ferrite is smaller than 53 mol%, the temperature at which the core loss in the ferrite could be the lowest will be higher than 110°C, thereby resulting in that the core loss in the ferrite within the intended temperature range increases. Depending on the ratio of Fe/Mn in the ferrite having an Fe_2O_3 content of from 54 to 55 mol%, the core loss in the ferrite could be the lowest at any temperature falling between 50 and 110°C. Therefore, in accordance with the intended temperature range for transformers, it is possible to select any desired composition of the ferrite in which the core loss could be lower within the temperature range. However, if the Fe_2O_3 content of the ferrite is larger than 55 mol%, the core loss in the ferrite could not be the lowest within a temperature range between 100 and 110°C and the minimum core loss in the ferrite will appear at lower temperatures than that range. If so, therefore, the core loss in the ferrite will increase within the intended temperature range.

[0031] The compositional range of the side components in the ferrite of the invention is defined essentially for the purpose of realizing the reduction in the core loss in the ferrite. If the amounts of the side components constituting the ferrite are outside the defined ranges, the core loss in the ferrite will increase. SiO_2 and CaO form an intergranular phase in the ferrite, while contributing to the increase in the resistance of the ferrite. Accordingly, if their amounts added to the ferrite are too small, their contribution to the resistance increase will be small; but if too large, they will cause abnormal grain growth in the ferrite whereby the core loss in the ferrite will increase. For these reasons, therefore, the amounts of SiO_2 and $CaCO_3$ to be added are defined to fall within the ranges noted above. Nb_2O_5 and ZrO_2 added to the ferrite along with SiO_2 and $CaCO_3$ act to prevent abnormal grain growth in the ferrite, while contributing to forming a thin and uniform high-resistance phase in the grain boundaries in the ferrite. In that manner, Nb_2O_5 and ZrO_2 act to further lower the core loss in the ferrite. However, if their amounts are larger than the defined ranges, the side components will cause abnormal grain growth in the ferrite, thereby increasing the core loss therein. If, on the contrary, their amounts are smaller than the defined ranges, the side components will be ineffective and could not contribute to the reduction in the core loss in the ferrite.

[0032]   The mean grain size of the ferrite may generally fall between 10 and 30 μm or so.

[0033]   In order to realize the reduction in the core loss in the ferrite, if desired, additional side components of tin oxide (its amount is calculated as SnO_2) and/or titanium oxide (its amount is calculated as TiO_2) may be added to the ferrite in an amount of not larger than 5000 ppm. However, the tetra-valent non-magnetic cations Sn and Ti may form solutes in the grains constituting the ferrite, thereby reducing Bs in the ferrite by a few %.

[0034]   The effect of the present invention characterized in that the core loss in the ferrite is low and Bs therein is high within the predetermined temperature range noted above is further augmented when the amounts of the components constituting the ferrite fall within the preferred ranges noted above.

[0035]   The transformer of the invention has a core which is made of the ferrite having the composition and the characteristics mentioned above, and is therefore well driven at a temperature falling between 60 and 120°C (preferably between 100 and 110°C), at a frequency falling between 20 and 500 kHz (preferably between 75 and 150 kHz) and in an exciting magnetic flux density falling between 200 and 500 mT (preferably between 200 and 350 mT).

[0036]   On the other hand, the ferrite having the composition mentioned below is characterized in that the absolute value of the temperature-dependent coefficient of Bs in the ferrite at a temperature falling between 20 and 120°C is not larger than 1.6 mT/°C. Therefore, the transformer of which the core is made of the ferrite can be driven in a broad temperature range falling between 20 and 120°C.

Essential Components:

[0037]

Iron oxide in an amount of from 53 to 55 mol% (calculated as Fe_2O_3),
Zinc oxide in an amount of from 2.0 to 8.0 mol%, preferably from 6.5 to 8.0 mol% (calculated as ZnO), and
Manganese oxide as the balance (calculated as MnO).

Side Components:

[0038]

Silicon oxide in an amount of from 60 to 200 ppm, preferably from 80 to 150 ppm (calculated as SiO_2),
Calcium oxide in an amount of from 300 to 1200 ppm, preferably from 600 to 1000 ppm (calculated as $CaCO_3$),
Niobium oxide in an amount of from 50 to 500 ppm, preferably from 150 to 400 ppm (calculated as Nb_2O_5), and
Zirconium oxide in an amount of from 10 to 450 ppm, preferably from 40 to 300 ppm (calculated as ZrO_2).

[0039]   The ferrite composition is characterized in that Bs therein is high within a temperature range falling between 20 and 120°C while linearly varying within the temperature range (see Fig. 2), that the temperature-dependent coefficient of Bs falls between -1.6 and 0 mT/°C, that the minimum core loss therein is within a high temperature range (falling between 90 and 120°C), and that the core loss therein is low at high temperatures. The temperature-dependent coefficient of Bs is represented by the following equation in which Bs [20°C] indicates the value of Bs at 20°C and Bs [120°C] indicates the value of Bs at 120°C.

Temperature-Dependent Coefficient, dBs/dT (T = 20 to 120°C)

$$= (Bs\ [120°C] - Bs\ [20°C])/(120°C - 20°C)$$

[0040]   Bs at a temperature falling between 20 and 120°C is at least 410 mT, preferably at least 415 mT, more preferably at least 420 mT. Though not specifically defined, the uppermost limit of Bs may be 500 mT or so.

[0041]   If the ZnO content of the ferrite is larger than 8.0 mol%, the absolute value of the temperature-dependent coefficient of Bs in the ferrite will be larger than 1.6. On the other hand, however, if the ZnO content of the ferrite is smaller than 2.0 mol%, the core loss in the ferrite will be too high.

[0042]   The ferrite core material for another embodiment of the transformers of the invention comprises a ferrite having the composition mentioned below, in which the saturation magnetic flux density Bs (direct current) at 60°C is not smaller than 480 mT, the core loss is the lowest within a temperature range falling between 50 and 70° C and the minimum core loss (at a frequency of 100 kHz) is not larger than 260 kW/m^3.

Essential Components:

[0043]

Iron oxide in an amount of from 54 to 56 mol%, preferably from 54.5 to 55 mol% (calculated as Fe_2O_3),
Zinc oxide in an amount of from 6 to 11 mol%, preferably from 6 to 9.5 mol%, even more preferably from 7.0 to 9.0 mol% (calculated as ZnO), and
Manganese oxide as the balance (calculated as MnO).

Side Components:

[0044]

Silicon oxide in an amount of from 80 to 150 ppm (calculated as SiO_2),
Calcium oxide in an amount of from 600 to 1000 ppm (calculated as $CaCO_3$),
Niobium oxide in an amount of from 150 to 400 ppm (calculated as Nb_2O_5), and
Zirconium oxide in an amount of from 40 to 300 ppm (calculated as ZrO_2).

[0045] The ferrite composition is characterized by high Bs at temperatures falling within the driving temperature range for transformers of from 50 to 70°C or so and by reduced core loss in the temperature range, as so mentioned hereinabove.
[0046] Therefore, using the core material of the ferrite of that type in producing transformer cores realizes high-efficiency transformers. More concretely, the ferrite cores in the transformers can be small-sized, and therefore the transformers themselves can be small-sized. In addition, since the core loss in the transformers is low, the power to be consumed by the transformers and also the heat to be generated by them can be reduced.
[0047] Bs (direct current) at 60°C in the ferrite having the composition mentioned above is not smaller than 480 mT, but preferably not smaller than 500 mT, more preferably not smaller than 505 mT. Though not specifically defined, the uppermost limit of Bs may be 600 mT or so.
[0048] The temperature range within which the core loss in the ferrite is the lowest, and also the minimum core loss in that temperature range are measured at a frequency falling between 20 and 500 kHz (preferably between 75 and 150 kHz) and in an exciting magnetic flux density falling between 125 and 500 mT (preferably between 200 and 350 mT). The core loss in the ferrite is the lowest within a temperature range falling between 50 and 70°C, and the minimum core loss (at 100 kHz and in 200 mT) is at most 260 kW/m^3, preferably at most 250 kW/m^3. Though not specifically defined, the lowermost limit of the core loss may be 100 kW/m^3 or so.
[0049] As opposed to the ferrite composition noted above, Bs in the others of which the composition of the essential components falls outside the ranges noted above could not be high, and the core loss in those will be high. The reason why the Fe_2O_3 content of the ferrite is defined to fall within the range noted above is as follows. In order that transformers could be most efficiently driven in power supplies and the like within the driving temperature range for the transformers, the core loss in the transformers shall be lowered within the driving temperature range, as so mentioned hereinabove. For this purpose, since the core loss in transformers varies depending on the temperature change therein, it is necessary that the core loss is the lowest within the temperature range within which the transformers are driven or around that temperature range (that is, the driving temperature range for transformers), and that the core loss is low within the driving temperature range. For this, it is well known to control the Fe_2O_3 content of the ferrite for transformer cores. If the Fe_2O_3 content is larger than 56 mol%, the core loss in the ferrite cores will be the lowest at temperatures lower than 50°C for the intended temperature range, or that is, the core loss therein will be high within the intended temperature range. Depending on the ratio of Fe/Mn in the ferrite having an Fe_2O_3 content of from 54 to 55 mol%, the core loss in the ferrite could be the lowest at any temperature falling between 50 and 110°C. Therefore, in accordance with the intended temperature range for transformers, it is possible to select any desired composition of the ferrite in which the core loss could be lower within the temperature range. However, if the Fe_2O_3 content of the ferrite is larger than 55 mol%, the minimum core loss in the ferrite may appear at lower temperatures, but when it is not larger than 56 mol%, the core loss in the ferrite will be reduced within the intended temperature range. On the other hand, however, if the Fe_2O_3 content is smaller than 54 mol%, the minimum core loss in the ferrite will appear at higher temperatures, thereby resulting in that the core loss will be high in the intended temperature range. The reason why the ZnO content of the ferrite is defined to fall within the above-mentioned range is because, if it is larger than 11 mol%, Bs in the ferrite will lower, and if smaller than 6 mol%, the core loss therein will increase.
[0050] The compositional range of the side components in the ferrite is defined essentially for the purpose of realizing the reduction in the core loss in the ferrite. If the amounts of the side components constituting the ferrite are outside the defined ranges, the core loss in the ferrite will increase. SiO_2 and CaO form an intergranular phase in the ferrite,

while contributing to the increase in the resistance of the ferrite. Accordingly, if their amounts added to the ferrite are too small, their contribution to the resistance increase will be small; but if too large, they will cause abnormal grain growth in the ferrite whereby the core loss in the ferrite will increase. For these reasons, therefore, the amount of SiO_2 to be in the ferrite is defined to fall between 80 and 150 ppm, and that of and $CaCO_3$ is defined to fall between 600 and 1000 ppm. Nb_2O_5 and ZrO_2 added to the ferrite along with SiO_2 and $CaCO_3$ act to prevent abnormal grain growth in the ferrite, while contributing to forming a thin and uniform high-resistance phase in the grain boundaries in the ferrite. In that manner, Nb_2O_5 and ZrO_2 act to further lower the core loss in the ferrite. However, if their amounts are larger than the defined ranges, the side components will cause abnormal grain growth in the ferrite, thereby increasing the core loss therein. If, on the contrary, their amounts are smaller than the defined ranges, the side components will be ineffective and could not contribute to the reduction in the core loss in the ferrite.

[0051]   Using Ta_2O_5 in place of Nb_2O_5 will increase the core loss in the ferrite.

[0052]   The mean grain size of the ferrite may generally fall between 10 and 30 μm or so.

[0053]   In order to realize the reduction in the core loss in the ferrite, if desired, additional side components of tin oxide (its amount is calculated as SnO_2) and/or titanium oxide (its amount is calculated as TiO_2) may be added to the ferrite in an amount of not larger than 5000 ppm. However, the tetra-valent non-magnetic cations Sn and Ti may form solutes in the grains constituting the ferrite, thereby reducing Bs in the ferrite by a few %.

[0054]   Cobalt oxide may also be added to the ferrite. In practical use, the cobalt oxide content of the ferrite could fall between 0 and 3000 ppm or so, calculated as Co_3O_4.

[0055]   The effect of the present invention characterized in that the core loss in the ferrite is low and Bs therein is high within the predetermined temperature range noted above is further augmented when the amounts of the components constituting the ferrite fall within the preferred ranges noted above.

[0056]   The transformer of the invention has a core which is made of the ferrite having the composition and the characteristics mentioned above, and is therefore well driven at a temperature falling between 50 and 70°C, at a frequency falling between 20 and 500 kHz (preferably between 75 and 150 kHz) and in an exciting magnetic flux density falling between 125 and 500 mT (preferably between 200 and 350 mT).

[0057]   To produce one embodiment of the ferrite cores for transformers of the invention, first prepared is a mixture of predetermined amounts of an iron oxide component, a manganese oxide component and a zinc oxide component. For the other embodiment of the ferrite cores for transformers of the invention, oxide cobalt may be added to the mixture in this stage.

[0058]   Compounds for the side components mentioned above are added to the mixture of the essential components. Their amounts shall be so controlled that the final mixture may have the predetermined compositional ratio. After the essential components and the side components have been mixed in that manner, a small amount of a suitable binder, for example, polyvinyl alcohol (PVA) is added thereto, and the resulting mixture is granulated, using a spray drier or the like, into grains having a grain size falling between 80 and 200 μm or so. Next, the grains are molded, and the resulting moldings are fired in an atmosphere having a controlled oxygen concentration, at a predetermined temperature falling between 1250 and 1400°C.

[0059]   The transformer of the invention may be produced by coiling a predetermined wire around the ferrite core having been molded in the manner mentioned above to have a predetermined shape. The shape and the size of the core may be varied, depending on the object and the use of the transformer to be produced. For example, the core may have any shape of toroidal forms, E-shaped forms, RM-shaped forms, ET-shaped forms, UU-shaped forms, FT-shaped forms, PQ-shaped forms, etc. The transformers of the invention can be small-sized. For example, for those suitable to use at high temperatures, the size of the core may be from 5 to 40 % smaller than that of conventional cores.

[0060]   The coiling count for the core may be varied, depending on the object and the use of the transformer to be produced.

[0061]   The transformer of the present invention can be used in switching power supplies for much small-sized and power-saving electronic appliances. In addition, the transformer is also usable in power supplies to be mounted on electric cars and hybrid cars.

[0062]   The invention is described in more detail hereinunder with reference to the following Examples, which, however, are not intended to restrict the scope of the invention.

Example 1:

[0063]   Essential components of Fe_2O_3, MnO and ZnO were weighed each in a predetermined amount as in Tables 1 and 2, wet-blended, and then calcined in air at 850°C for 2 hours. Depending on the amounts of the essential components, predetermined amounts of side components of SiO_2, $CaCO_3$, Nb_2O_5 and ZrO_2 were added to the resulting mixture, and wet-milled to obtain a ferrite powder. 0.8 % by weight, calculated as its solid content, of a binder of PVA was added to the powder, and granulated. The resulting grains were molded under a pressure of 1 ton/cm^2 into toroidal moldings (outer diameter: 24 mm, inner diameter: 12 mm, thickness: 5.5 mm). The moldings were fired in a mixed gas

atmosphere of N_2-O_2 having a controlled oxygen partial pressure, at a firing temperature of 1300°C for 5 hours. Thus were obtained toroidal cores having an outer diameter of 20 mm, an inner diameter of 10 mm and a thickness of 5 mm. Through its fluorescent X-ray spectrometry, the final ferrite composition was verified to correspond to the composition of the starting components.

[0064]   Each sample obtained herein was tested in an alternating current B-H analyzer (IWATSU-SY8232) for the core loss therein at an exciting magnetic flux density of 200 mT and at a frequency of 100 kHz. In addition, it was tested in a direct current B-H analyzer (YEW4192) for the saturation magnetic flux density Bs therein in a magnetic field of 15 Oe and at a temperature of 120° C.

[0065]   Tables 1 and 2 show the data of Bs and the minimum core loss in each sample, and the temperature at which the core loss was minimized. Fig. 1 shows the temperature-dependent variation in the core loss in Samples Nos. 103 and 104 (samples of the invention), and Sample No. 106 (conventional sample).

Table 1

Sample No.	Essential Components (mol%)			Side Components (ppm)				Bs (120°C) (mT)	Minimum Core Loss (kW/m³)	Temperature for Minimum Core Loss (°C)
	Fe₂O₃	ZnO	MnO	SiO₂	CaCO₃	Nb₂O₅	ZrO₂			
101	53.8	9.0	37.2	100	800	300	250	415	258	100 - 110
102	53.9	8.5	37.6	100	800	300	250	420	262	100 - 110
103	54.0	8.0	38.0	100	800	300	250	428	258	100 - 110
104	54.1	7.5	38.4	100	800	300	250	432	260	100 - 110
105	54.2	6.5	39.3	100	800	300	250	437	265	100 - 110
106 (comp.)*	53.5	10.0	36.5	100	800	300	250	390	320	90 - 100
107 (comp.)	53.7	10.0	36.3	100	800	300	250	400	320	100 - 110
108 (comp.)	53.5	11.3	35.2	85	950	360	0	370	412	90 - 100
109 (comp.)	53.4	12.0	34.6	100	800	300	250	384	332	100 - 110
110 (comp.)	55.0	0.0	45.0	100	800	300	250	433	518	100 - 110
111 (comp.)	54.0	8.0	38.0	50	800	300	250	421	367	100 - 110
112 (comp.)	54.0	8.0	38.0	300	800	300	250	415	872	100 - 110
113 (comp.)	54.0	8.0	38.0	100	200	300	250	403	414	100 - 110

* SnO_2 2500 ppm added

Table 2

Sample No.	Essential Components (mol%)			Side Components (ppm)				Bs (120°C) (mT)	Minimum Core Loss (kW/m³)	Temperature for Minimum Core Loss (°C)
	Fe_2O_3	ZnO	MnO	SiO_2	$CaCO_3$	Nb_2O_5	ZrO_2			
114 (comp.)	54.0	8.0	38.0	130	1430	300	250	434	363	100 - 110
115 (comp.)	54.0	8.0	38.0	100	800	0	250	418	402	100 - 110
116 (comp.)	54.0	8.0	38.0	100	800	700	250	418	819	100 - 110
117 (comp.)	54.0	8.0	38.0	100	800	300	0	423	302	100 - 110
118 (comp.)	54.0	8.0	38.0	100	800	300	600	418	648	90 - 110
119**	53.8	8.0	38.2	100	800	300	250	415	260	100 - 110
120	54.0	8.0	38.0	100	800	200	250	434	250	100 - 110
121	54.0	8.0	38.0	100	800	300	150	433	258	100 - 110
122	54.0	8.0	38.0	130	650	300	250	437	256	100 - 110

** SnO_2 3000 ppm added

[0066] From the data in Tables 1 and 2 and Fig. 1, it is known that the saturation magnetic flux density in the samples of the invention is high at high temperatures and that the core loss therein is extremely low at a temperature falling between 100 and 110°C.

[0067] Specifically, it is known that the core loss in the ferrite cores for transformers of the present invention is low and the saturation magnetic flux density therein is high, as compared with those in the conventional ferrite core for transformers of Sample No. 106. As realizing such high saturation magnetic flux density, the ferrite cores for transformers of the invention can be small-sized and even the transformers themselves of the invention can also be small-sized.

[0068] Using the ferrite core of Sample No. 103 of the invention, produced was a transformer.

[0069] Briefly, the ferrite core was PQ-shaped, and its size was 59 mm x 42 mm x 27 mm (metatarsal diameter: 24 mm). For the coiling count for the core, the primary coil was in one turn, and the secondary coil was in 4 turns.

[0070] The transformer was found to be well driven at a temperature of 110°C, at a frequency of 100 kHz and in an exciting magnetic flux density of 200 mT.

[0071] In addition, it was found that ferrite core of the invention is more small-sized than the conventional ferrite core of Sample No. 106 (by about 10 % calculated as the cross section of the core). Moreover, it was further found that the power to be consumed by the transformer of the invention was reduced and that the heat as generated by the transformer being driven was lowered.

Example 2:

[0072] In the same manner as in Example 1, prepared were ferrite core samples (toroidal cores) for transformers, each having the composition shown in Table 3. Also in the same manner as in Example 1, Bs in those samples was measured.

[0073] The data obtained are in Table 3.

Table 3

Sample No.	Essential Components (mol%)			Side Components (ppm)				Bs (120°C) (mT)
	Fe_2O_3	ZnO	MnO	SiO_2	$CaCO_3$	Nb_2O_5	ZrO_2	
201	54.2	6.0	39.8	100	800	300	250	428
202	54.4	5.0	40.6	100	800	300	250	438
203	54.5	4.5	41.0	100	800	300	250	438

[0074] In the samples of the invention, Bs linearly decreased with the increase in the ambient temperature of 100°C to 110°C to 120°C. From the data in Table 3, it is known that Bs in those samples is not lower than 410 mT within a temperature range of from 100 to 120°C. The core loss in those samples was low at temperatures of from 100 to 110°C. Example 3:

[0075] In the same manner as in Example 1, prepared were ferrite core samples (toroidal cores) for transformers, each having the composition shown in Tables 4 and 5. Also in the same manner as in Example 1, Bs in those samples was measured. In this, however, the samples were tested at an ambient temperature falling between 20 and 120°C. Tables 4 and 5 show the data of Bs and the temperature-dependent coefficient of Bs, dBs/dT (T = 20 to 120°C). Fig. 2 shows a graph of the temperature-dependent variation in Bs in Sample No. 301 (sample of the invention, this is the

same as Sample No. 103 in Example 1) and in a conventional sample (Sample No. 309, this is the same as Sample No. 106 in Example 1).

Table 4

Sample No.	Essential Components (mol%)			Side Components (ppm)				Bs (120°C) (mT)	dBs/dT (T=20 to 120°C)
	Fe_2O_3	ZnO	MnO	SiO_2	$CaCO_3$	Nb_2O_5	ZrO_2		
301	54.0	8.0	38.0	100	800	300	250	428	-1.55
302	54.1	7.5	38.4	100	800	300	250	432	-1.52
303	54.2	6.5	39.3	100	800	300	250	437	-1.29
304	54.2	6.0	39.8	100	800	300	250	428	-1.27
305	54.4	5.0	40.6	100	800	300	250	438	-1.18
306	54.5	4.5	41.0	100	800	300	250	438	-1.17
307	54.7	3.0	42.3	100	800	300	250	438	-1.06
308	55.0	2.0	43.0	100	800	300	250	437	-0.94
309* (comp.)	53.5	10.0	36.5	100	800	300	250	390	-1.61
310	54.0	8.0	38.0	100	800	100	250	424	-1.41
311	54.0	8.0	38.0	100	800	200	250	434	-1.40

*SnO_2 2500 ppm added

Table 5

Sample No.	Essential Components (mol%)			Side Components (ppm)				Bs (120°C) (mT)	dBs/dT (T=20 to 120°C)
	Fe_2O_3	ZnO	MnO	SiO_2	$CaCO_3$	Nb_2O_5	ZrO_2		
312	54.0	8.0	38.0	100	800	300	150	433	-1.41
313	54.0	8.0	38.0	100	800	300	350	426	-1.35
314	54.0	8.0	38.0	100	800	100	100	424	-1.44
315	54.0	8.0	38.0	100	800	200	150	428	-1.40
316	54.0	8.0	38.0	100	500	300	250	423	-1.42
317	54.0	8.0	38.0	130	650	300	250	437	-1.40
318	54.0	8.0	38.0	70	560	300	250	433	-1.40
319	54.0	8.0	38.0	130	1040	300	250	434	-1.39

[0076] From the data in Tables 4 and 5 and Fig. 2, it is known that the samples of the invention have a negative temperature-dependent coefficient of Bs, that the absolute value of the temperature-dependent coefficient is not larger

than 1.6 mT/°C, and that Bs in the samples is high at temperatures of from 20 to 120°C. The core loss in those samples was small at temperatures of from 100 to 110°C.

Example 4:

[0077] Essential components of Fe_2O_3, MnO and ZnO were weighed each in a predetermined amount as in Tables 6 and 7, wet-blended, and then calcined in air at 850°C for 2 hours. Depending on the amounts of the essential components, predetermined amounts of side components of SiO_2, $CaCO_3$, Nb_2O_5 and ZrO_2 were added to the resulting mixture, and wet-milled to obtain a ferrite powder. 0.8 % by weight, calculated as its solid content, of a binder of PVA was added to the powder, and granulated. The resulting grains were molded under a pressure of 1 ton/cm^2 into toroidal moldings (outer diameter: 24 mm, inner diameter: 12 mm, thickness: 5.5 mm). The moldings were fired in a mixed gas atmosphere of N_2-O_2 having a controlled oxygen partial pressure, at a firing temperature of 1300°C for 5 hours. Thus were obtained toroidal cores having an outer diameter of 20 mm, an inner diameter of 10 mm and a thickness of 5 mm. Using Ta_2O_5 in place of Nb_2O_5, a different core sample was produced in the same manner as herein. Through its fluorescent X-ray spectrometry, each final ferrite composition was verified to correspond to the composition of the starting components.

[0078] Each core sample obtained herein was tested in an alternating current B-H analyzer (IWATSU-SY8232) for the core loss therein at an exciting magnetic flux density of 200 mT and at a frequency of 100 kHz. In addition, it was tested in a direct current B-H analyzer (YEW4192) for the saturation magnetic flux density Bs therein in a magnetic field of 15 Oe and at a temperature of 60°C.

[0079] Tables 6 and 7 show the data of Bs and the minimum core loss in each sample, and the temperature at which the core loss was minimized.

Table 6

Sample No.	Essential Components (mol%)			Side Components (ppm)				Bs (60°C) (mT)	Minimum Core Loss (kW/m³)	Temperature for Minimum Core Loss (°C)
	Fe_2O_3	ZnO	MnO	SiO_2	$CaCO_3$	Nb_2O_5	ZrO_2			
401	54.6	9.0	36.4	100	800	300	250	515	234	60
402	54.8	8.0	37.2	100	800	300	250	520	240	60
403	54.9	7.0	38.1	100	800	300	250	518	247	60
404	54.8	9.0	36.2	100	800	300	250	507	246	50
405	55.0	8.0	37.0	100	800	300	250	522	242	50
406	55.1	7.0	37.9	100	800	300	250	524	256	50
407	54.4	10.0	35.6	100	800	300	250	493	250	60
408	54.4	11.0	34.6	100	800	300	250	486	240	50
409 (comp.)	55.2	5.0	39.8	100	800	300	250	499	291	60
410 (comp.)	54.0	12.0	34.0	100	800	300	250	460	253	60
411 (comp.)	56.2	8.0	35.8	100	800	300	250	524	764 (255)*	10

* The core loss at 60 °C and that at the temperature for minimum core loss are shown. The latter is parenthesized.

Table 7

Sample No.	Essential Components (mol%)			Side components (ppm)				Bs (60°C) (mT)	Minimum Core Loss (kW/m³)	Temperature for Minimum Core Loss (°C)
	Fe_2O_3	ZnO	MnO	SiO_2	$CaCO_3$	Nb_2O_5	ZrO_2			
412 (comp.)	54.8	8.0	37.2	50	800	300	250	521	341	60
413 (comp.)	54.8	8.0	37.2	300	800	300	250	514	811	60
414 (comp.)	54.8	8.0	37.2	100	200	300	250	513	385	60
415 (comp.)	54.8	8.0	37.2	130	1430	300	250	537	338	60
416 (comp.)	54.8	8.0	37.2	100	800	0	250	518	374	60
417 (comp.)	54.8	8.0	37.2	100	800	700	250	518	762	60
418 (comp.)	54.8	8.0	37.2	100	800	300	0	524	290	60
419 (comp.)	54.8	8.0	37.2	100	800	300	600	518	603	60
420 (comp.)	54.8	8.0	37.2	100	800	—** (Ta_2O_5 300ppm)	250	518	285	60

**) Nb_2O_5 was not added, but 300 ppm of Ta_2O_5 was added.

[0080] From the data in Tables 6 and 7, it is known that Bs in the samples of the invention is high within a temperature range (50 to 70°C) within which transformers may be driven and that the core loss therein is low within the driving temperature range.

[0081] As opposed to those, the core loss in the sample having a ZnO content of smaller than 6 mol% is high (Sample No. 409), and Bs in the sample having a ZnO content of larger than 11 mol% is low (Sample No. 410). In the sample having an Fe_2O_3 content of larger than 56 mol%, the minimum core loss appears at a low temperature, and the core loss at temperatures around the driving temperature range is high (Sample No. 411). In the samples in which the amounts of the side components all overstep the ranges defined herein, the core loss at temperatures around the driving temperature range is high (Samples Nos. 413 to 419). In the sample containing Ta_2O_5 in place of Nb_2O_5, the core loss is high (Sample No. 420). In ferrite cores having an Fe_2O_3 content of smaller than 54 mol%, the minimum core loss appears within a temperature range of from 100 to 110°C, like in Sample No. 101 (Table 1) in Example 1; and the core loss in those cores within the driving temperature range is high (for example, 431 kW/m^3 at 60°C). Therefore, the ferrite cores having such a small Fe_2O_3 content are not suitable to use in transformers to be driven within the temperature range of from 50 to 70°C.

Example 5:

[0082] To the composition of Sample 402 in Example 4 (Table 6), cobalt oxide was added in an amount of 2000 ppm calculated as Co_3O_4 to prepare Sample No. 402A. In this, cobalt oxide was mixed with the essential components, Fe_2O_3, MnO and ZnO prior to being calcined.

[0083] The sample was evaluated for its characteristics in the same manner as in Example 4. The data obtained are shown in Table 8.

Table 8

Sample No.	Bs (60°C) (mT)	Minimum Core Loss (kW/m^3)	Temperature of Minimum Core Loss (° C)
2A (cobalt oxide added)	520	260	60

[0084] The data in Table 8 verify the practical level of this sample.

Example 6:

[0085] Using the ferrite core of Sample No. 401 in Example 4 of the invention, produced was a transformer A.

[0086] Briefly, the ferrite core was PQ-shaped, and its size was 59 mm x 42 mm x 27 mm (metatarsal diameter: 24 mm). For the coiling count for the core, the primary coil was in one turn, and the secondary coil was in 4 turns.

[0087] The transformer A was found to be well driven at a temperature of 60° C, at a frequency of 100 kHz and in an exciting magnetic flux density of 200 mT.

[0088] According to the present invention, obtained are ferrites in which the core loss is low and Bs is high at high temperatures. Also obtained are transformers capable of being small-sized and suitable to use at high temperatures. The transformers can be efficiently driven even at high temperatures. In addition, the transformers are suitable to use in a broad temperature range including high temperatures, and can be small-sized.

[0089] Also according to the invention, obtained are high-efficiency transformers capable of being small-sized, in which the core loss in the ferrite core is low and the saturation magnetic flux density is high therein at the temperature at which the transformers are driven. The transformers of the invention can be efficiently driven according to the driving method for them of the invention.

[0090] While the invention has been described in detail and with reference to specific embodiments thereof, it will be apparent to one skilled in the art that various changes and modifications can be made therein without departing from the spirit and scope thereof.

Claims

1. A transformer of which the core is made of a ferrite that consists essentially of iron oxide in an amount of from 54 to 56 mol% calculated as Fe_2O_3, zinc oxide in an amount of from 6 to 11 mol% calculated as Zn0, and manganese oxide, and contains, as side components, silicon oxide in an amount of from 80 to 150 ppm calculated as SiO_2,

calcium oxide in an amount of from 600 to 1000 ppm calculated as $CaCO_3$, niobium oxide in amount of from 150 to 400 ppm calculated as Nb_2O_5, and zirconium oxide in an amount of from 40 to 300 ppm calculated as ZrO_2, and in which the saturation magnetic flux density (direct current) in the ferrite at 60°C is not smaller than 480 mT, the minimum core loss in the ferrite is within a temperature range falling between 50 and 70°C and the minimum core loss (at a frequency of 100 kHz) is not larger than 260 kW/m^3.

2. A transformer as claimed in Claim 1 wherein the zinc oxide content of the ferrite falls between 6 and 9.5 mol% calculated as ZnO.

3. A transformer as claimed in claim 1 or claim 2,
   wherein the saturation magnetic flux density (direct current) in the ferrite at 60°C is not smaller than 500 mT.

4. A method for driving a transformer as claimed in any one of claims 1 to 3 comprising driving the transformer at a temperature falling between 50 and 70°C, at a frequency falling between 20 and 500 kHz and in an exciting magnetic flux density falling between 125 and 500 mT.
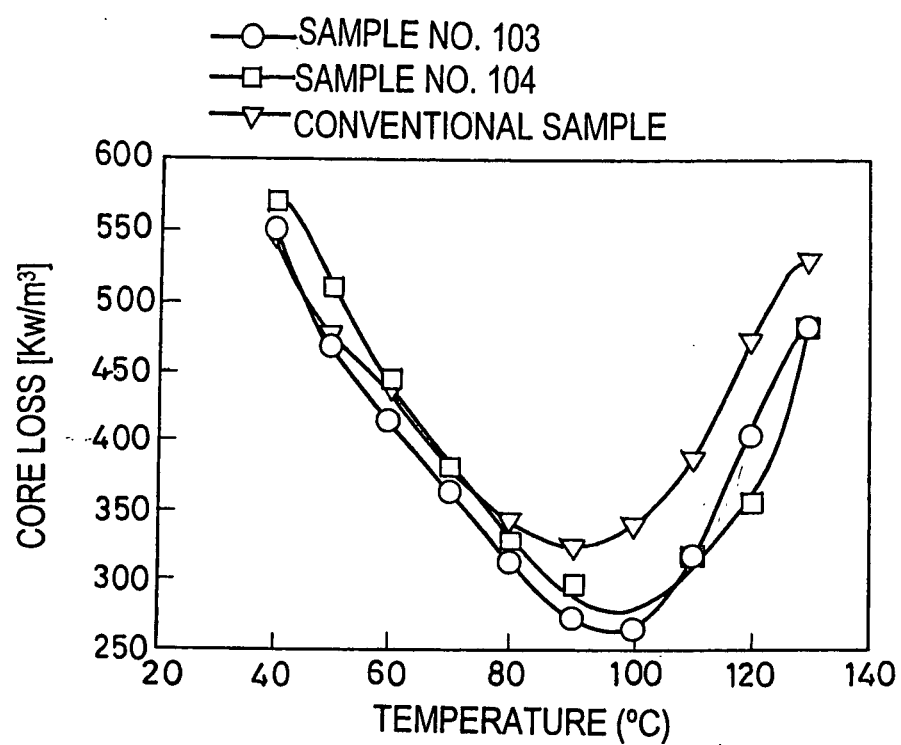
FIG. 1

- —○— SAMPLE NO. 103
- —□— SAMPLE NO. 104
- —▽— CONVENTIONAL SAMPLE

FIG. 2